EVALUATION OF PERFORMANCE AND SAFETY OF ELECTROFUEL LITHIUM-ION POLYMER CELLS

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Abstract

Lithium-ion batteries of the conventional and polymer type are being used widely for cellular phones, cameras, camcorders, personal computers, PDAs and in several other portable electronic equipment. The Electrofuel li-ion polymer battery is one of the first available polymer batteries to be used for commercial applications. In our study, the tests carried out on these cells were aimed at determining if these batteries can be used in extravehicular activity tools for both Shuttle and International Space Station.

Introduction

Since the discovery of $LiCoO_2$ cathode by Goodenough and coworkers in 1980, the secondary li-ion battery technology has advanced greatly.[1] The demand for lightweight, compact secondary batteries for space, civilian and military applications is always increasing. Present development in the field of lithium polymer cells is directed towards lithium-ion[2] (carbon-intercalated lithium) and lithium-metal polymer electrolyte[3] high energy density batteries. Lithium-ion polymer batteries are currently being produced for consumer electronic applications. Arthur D. Little, Bellcore and Ultralife were the first ones to develop cells with solid polymer or gel electrolytes containing dielectric organic solvents, which also served as separators. In the past few years several other commercial cell manufacturers have presented information on their polymer li-ion cells.[4,5,6] Performance and abuse test results, of one kind of li-ion polymer cell, was presented at meetings by our group in the past two years.[7] The Electrofuel lithium-ion polymer cells were one of the first polymer cells to be commercialized for portable electronic equipment like laptops. The lightweight, flat and compact structure make them a good candidate for several weight and volume critical space applications. In this study, the Electrofuel cells were tested to determine their performance and abuse tolerances. Physical, electrochemical and safety tests were performed on these cells.

Experimental

The Electrofuel PowerPad 160™ batteries were purchased and the cells removed from them for testing. The Maccor 4000 with a multirange software was used for the tests. The environmental tests were performed with an Associated environmental chamber with a Watlow controller. Discharge into reversal tests were carried out with power supplies and diodes.

Results and Discussion

The cells were subjected to the tests described below.

Physical and Electrochemical Characterization.

Dimensions and weight.

The cells have an average dimension of 4.008 in. (height) by 5.269 in. (width) by 0.366 in.(thickness). The weights of the cells ranged from 234.8 to 244.7 grams with an average of 240.18 grams and a standard deviation of 2.59 g.

The Open Circuit Voltage (OCV).

The OCV of the cells were measured and recorded. The open circuit voltage was consistent with an average voltage of 3.7596 V with a standard deviation of 0.0135 V. The range varied between 3.7434 to 3.7815 V.

Closed Circuit Voltage (CCV)

The CCV test was performed with a current of approximately 16.5 A (1.5 C) for 30 seconds. The cells averaged a CCV of 3.152 V with a standard deviation of 0.058 V. The range varied between 3.0513 to 3.2698 V.

Capacity Measurement

All cells were subjected to one charge/discharge cycle before they were subjected to further testing. The cells were charged using the constant current/constant voltage protocol where the cells were charged using a C/7 current of approximately 1.6 A to 4.1 V and then held at a constant voltage of 4.1 V until the current dropped to about 100 mA. Discharge was at C/7 rate (1.6 A) to a cutoff voltage of 3.0 V. The average capacity was 9.546 Ah with a standard deviation of 0.528 Ah.

Performance Tests.

Rate Capability.

The performance test protocols involved different rates of charge/ discharge cycling as given in Table 1 to determine the optimum charge/discharge rates. The test was stopped when the cells dropped in capacity to below 4.0 Ah. The charging was performed with a given current to 4.2 V and then changed to constant voltage until the current dropped to 100 mA. Discharge was performed to 3.0 V using the appropriate current. Figure 1 gives the cycle life performance data for a C/7 charge and C/4 discharge.

Table 1: Charge /Discharge Rate Protocols Used in the Cycle Life Test.

Charge Rate	Dicharge Rate
0.1C (1.1 A)	0.1C (1.1 A)
Approx. 0.5C (5.0 A)	0.25 C (2.75 A)
Approx 0.5 C (5.0 A)	0.15 C (1.6 A)
0.15C (1.6 A)	0.1C (1.1 A)
0.15 C (1.6 A)	0. 25C (2.75 A)
0.15 C (1.6 A)	0.15 C (1.6 A)

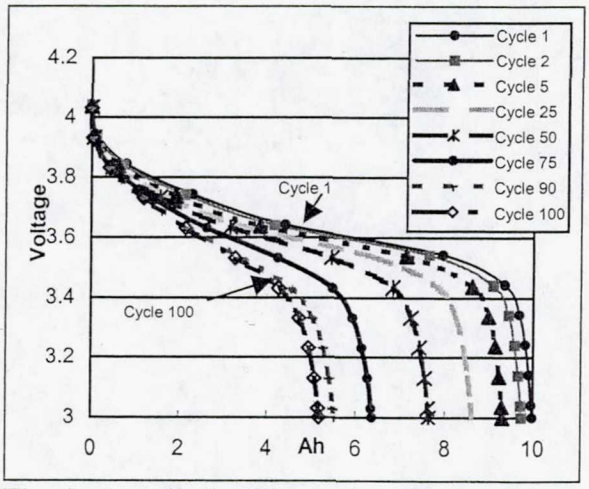

Figure 1. Cycle life testing for a typical Electrofuel cell at C/7 Charge and C/4 Discharge.

Performance at different temperatures.

Four cells underwent five cycles at four different temperatures of 0, 25, 45 and 65 °C. The cells were all charged at ambient temperature. The cells were soaked at the

appropriate temperatures for approximately one hour before discharge. The cells were then discharged with 1.6 A to 3.0 V. Some capacity degradation was evident for all temperature conditions after the five cycles. The capacity degradation was greatest at the low temperatures and was least at the highest temperature (Figure 2). The capacity peaked at +45 °C although +25 °C was approximately the same. At 0 °C the capacity was 10% lower than the maximum capacity (+45 °C) on cycle 5.

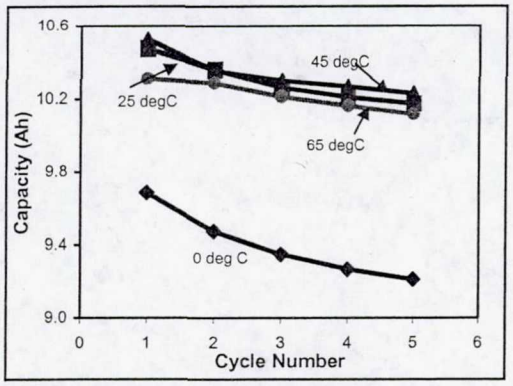

Figure 2. Performance of the Electrofuel cell at different temperatures.

Effective Internal Resistance.

Two cells were subjected to an effective internal resistance test. After three normal charge/discharge cycles, one cycle of dynamic internal resistance measurements versus the state of charge for the cell was performed. For this, the cell was charged using the CC/CV protocol and then discharged at 10 % intervals of state of charge using high current pulses (1C). The internal cell resistance between 20-90 % SOC was 50-55 mohms for the two cells tested.

Safety Tests.

Overcharge.

A cell was charged to 4.5 V using a current of 1.6 A. The voltage was maintained for two hours. The peak temperature for this test was 17.3 °C after 2 hours, an increase of 1.5 °C over the ambient. There was no venting or noticeable expansion of the cell during this test.

The same cell was charged to 5.0 V using a current of 1.6 A and the voltage maintained for twelve hours (Figure 3). The peak temperature obtained was 22.5 °C, an increase of 5 °C over room temperature. No significant venting occurred; however, there was expansion of the cell thickness to approximately 1 inch. No weight loss was observed. The capacity delivered during discharge after the overcharge test was 15.55 Ah.

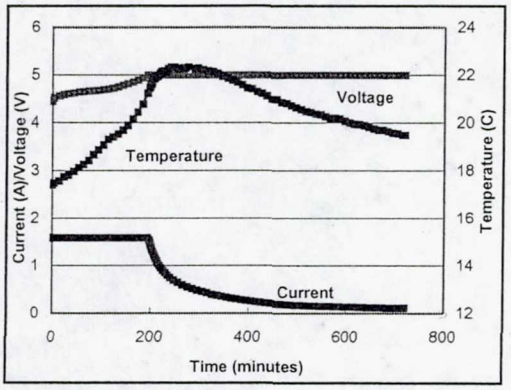

Figure 3. Overcharge Test on the Electrofuel li-ion polymer cell.

Overdischarge.

Fully charged cells were discharged with 1.6 A current to 2.5 V/cell, 2.0 V/cell and 1.0 V/cell and held at each voltage for 60 minutes. The cells were then discharged to 0 V and then further taken into reversal for 150 % of the 1C capacity and held at that voltage for at least two hours. The first part of the test to 0 V was uneventful. In the reversal portion of the test, the peak temperature observed was 29 °C after approximately 1 hour. There were no obvious signs of venting and this was confirmed by the weight loss of 0.1 g, which was within the limit of error for the scale used.

High Temperature Exposure and Heat-to-Vent.
Fully charged and weighed cells were exposed to 150 °F for 2 hours. The test was uneventful with the exception of a mild ether like odor at a temperature of ~240 °C and a significant cell expansion. Scorching of the paper cell wrapper on the top side only was observed with no obvious evidence of the cell venting other than a weight loss of 10.5g.
External Short Circuit. Fully charged cells were shorted using a 0.03 ohm and 0.05 ohm resistor (one cell each). For the 0.05 ohm test, the initial momentary current draw was calculated to be in the order of 38 A (Figure 4). The initial current then quickly dropped to approximately 15 A and tapered at a slower rate to 3 A after 30 minutes.

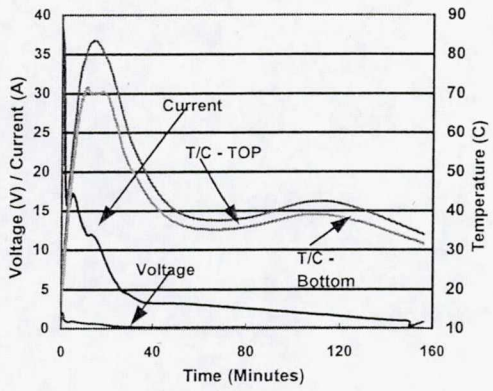

Figure 4. External Short Test on the Electrofuel cell with a 0.05 ohm resistor.

The temperature began to rise shortly after the resistor was attached and peaked at 83 °C after about 20 minutes. The temperature stabilized at 37 °C after 60 minutes and increased to 42 °C after 120 minutes. The temperature again dropped off slowly until the test was discontinued. There was no significant venting. The weight loss was measured to be 0.15 g and was within the limits of error for the balance. For the 0.03 ohm test, the initial momentary current draw captured was 62 A and the maximum temperature observed was 75 °C which was after ten minutes into the test.

Summary.

The performance tests on the Electrofuel li-ion polymer cells show that these cells perform well at low rates of charge and discharge. The safety tests show that they are safe under most abusive conditions as expected of polymer batteries although expansion of the cells occurs in most cases.

Acknowledgment.
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